Underground needs for gravitational wave experiments

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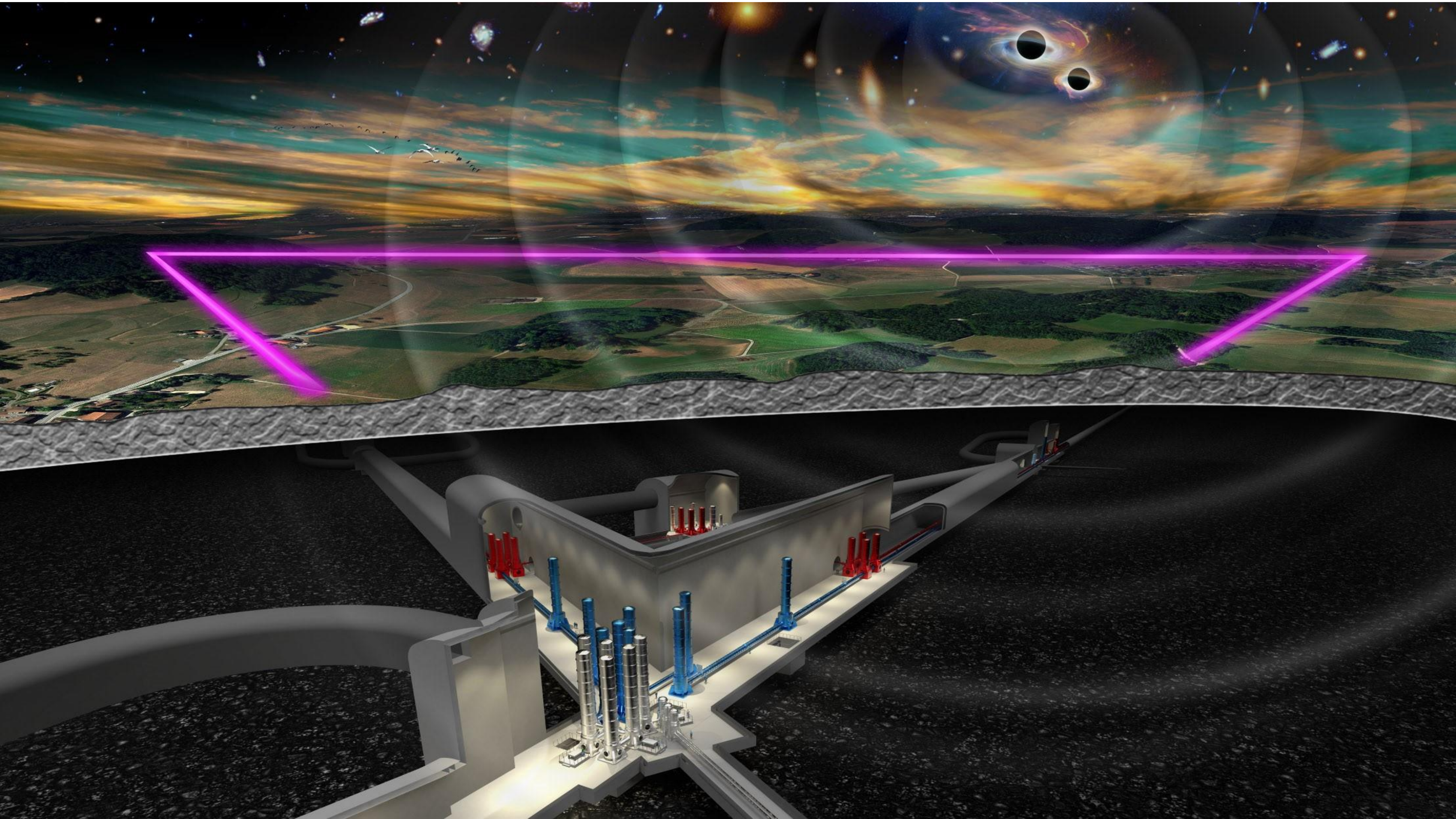
Snowmass Community Planning Meeting, October 5, 2020



Contents

Science

Gravity is a fundamental interaction with most important open scientific issues

Strong scientific interest from HEP community

Underground facility can be share with other communities, e.g. geoscience

Advanced detectors and future observatories

Quality of gravitational wave science is determined by the sensitivity of our observatories

Future observatories are under study: Einstein Telescope and Cosmic Explorer

Gravitational Waves and (European) HEP community

LIGO and Virgo are CERN-recognized experiments

MOU between CERN – INFN – Nikhef on instrumentation for Einstein Telescope

Interactions have started on R&D for vacuum instrumentation

Examples for joint R&D on instrumentation

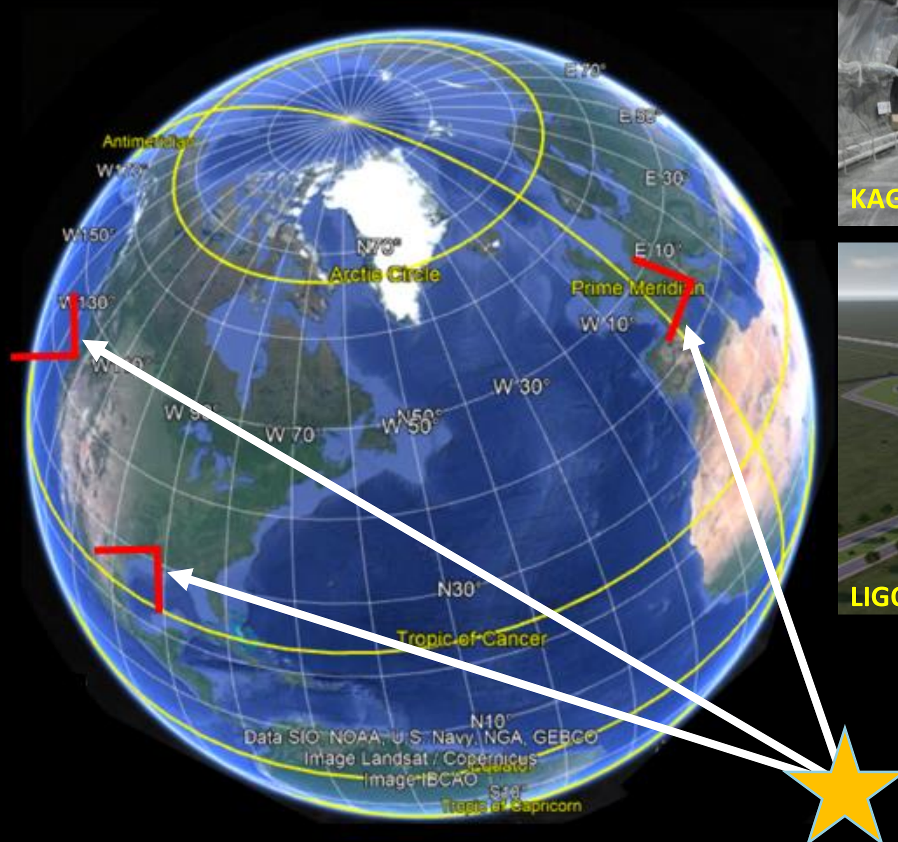
Underground construction

Vacuum beam-tube construction, cleaning & bake out procedure

Cryogenics, controls

Internal Gravitational Wave observatory Network

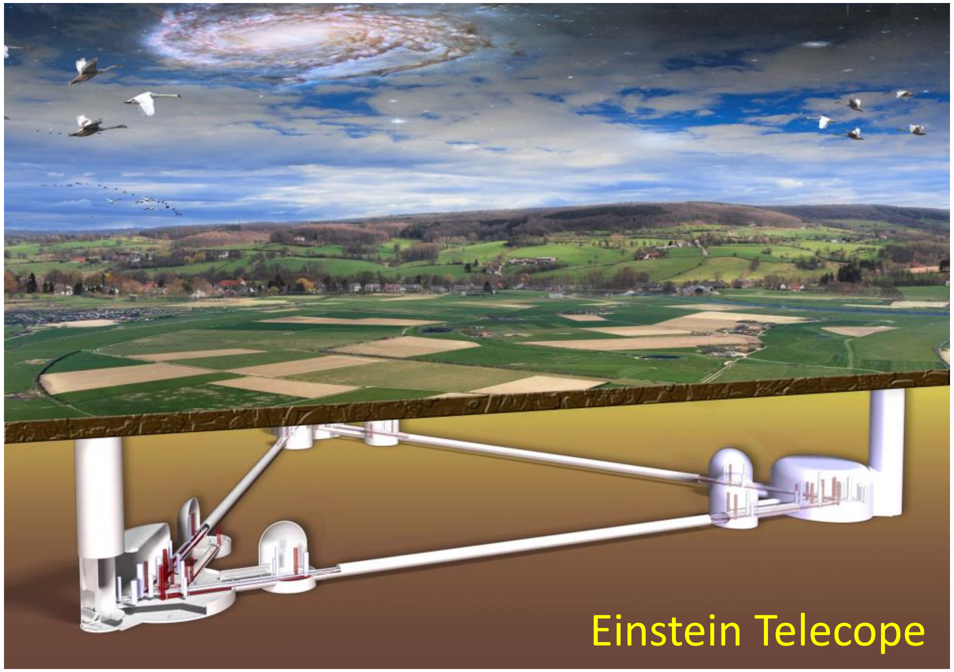
IGWN will feature full sky coverage and best possible sky localization

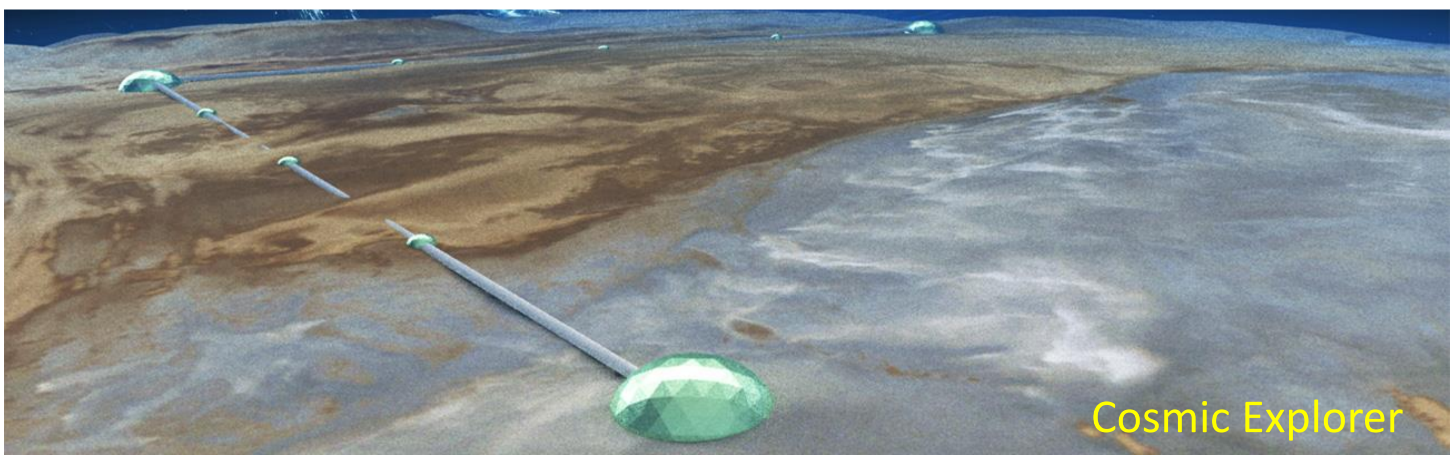


Observation run O3 (1 year run that ended on April 2020) showed close to weekly alerts of gravitational wave events by LIGO and Virgo (mostly black hole mergers)

Future: Einstein Telescope and Cosmic Explorer

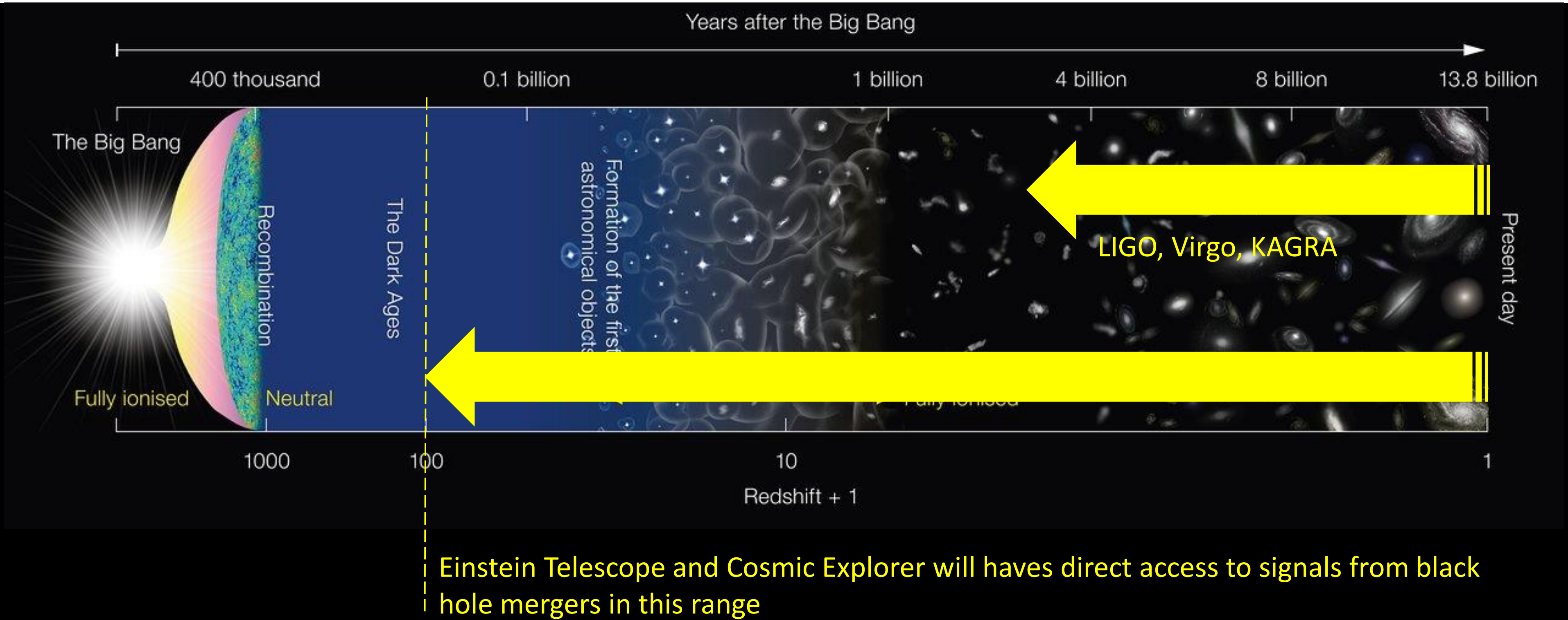
Proposal for Einstein Telescope was submitted in September 2020 to ESFRI, the European Strategy Forum on Research Infrastructures. A Conceptual Design Study for Cosmic Explorer is underway





Detection horizon for black hole binaries

Einstein Telescope and Cosmic Explorer can observe BBH mergers to redshifts of about 100. This allows a new approach to cosmography. Study primordial black holes, BH from population III stars (first metal producers), *etc*.



These third-generation instruments will observe hundreds of thousands of black hole mergers per year

Many events will have signals with an SNR up to 1,000 allowing precision black hole science

Events are distributed through the entire Universe allowing cosmography

Sensitivity of Einstein Telescope compared to Virgo

Einstein Telescope will feature excellent low-frequency sensitivity and have great discovery potential

Low frequency sensitivity
GW signals detected at high redshift will appear at low frequency

Signals from more massive black holes will appear at low frequency

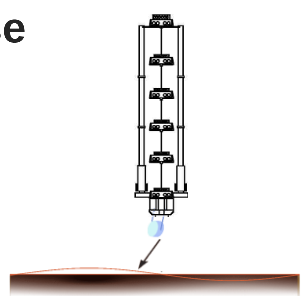
Intermediate mass black holes are important new sources

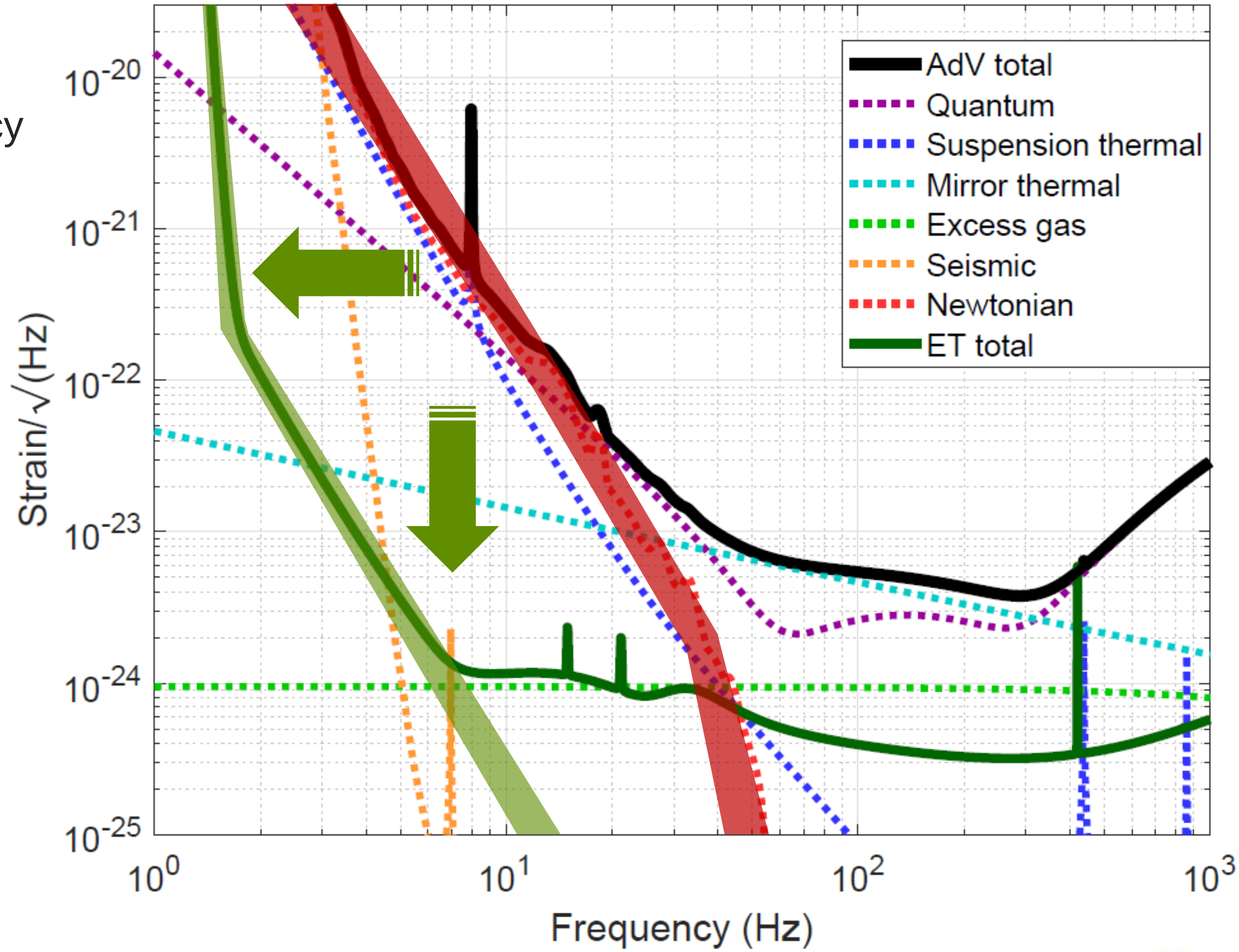
Early warning systems will profit enormously from low frequency

Observation of spin precession profits from longer observation

Low frequency noise
Seismic noise

Newtonian noise





Infrastructure design

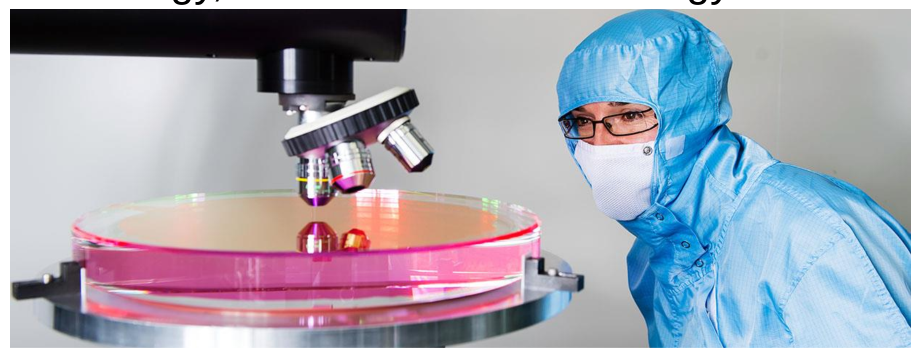
Key technologies

GW requires many of the technologies developed for particle physics: underground construction, vacuum and cryogenic technology, advanced controls

The particle physics community (e.g. CERN) has build up vast expertise in governance and implementation of big science projects. Gravitational wave community should build on this

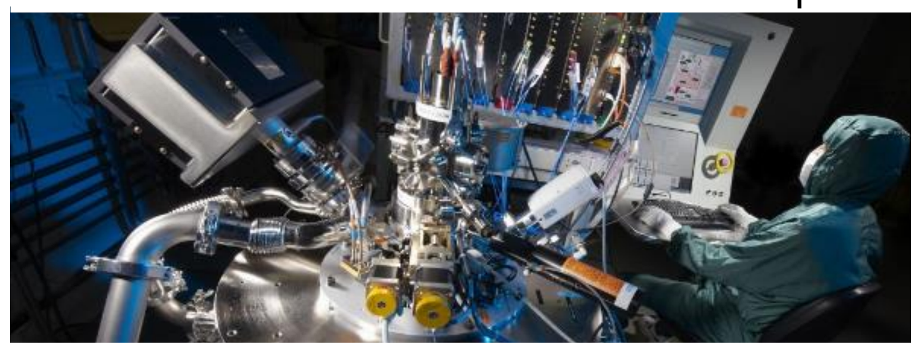
Measuring and attenuating vibrations: nano-technology, medical, defense

Optics, coatings, special materials, laser technology, semiconductor technology



Vacuum technology: 3G will feature the biggest vacuum systems worldwide

Cryogenic systems: KAGRA/ET's low frequency interferometer will feature cooled silicon optics



Einstein Telescope design

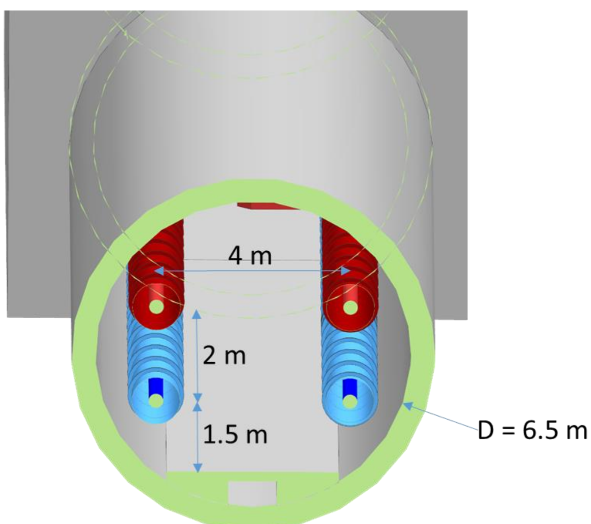
Three detectors that each consist of two interferometers:
6 ITFs in total, few hundred meters underground

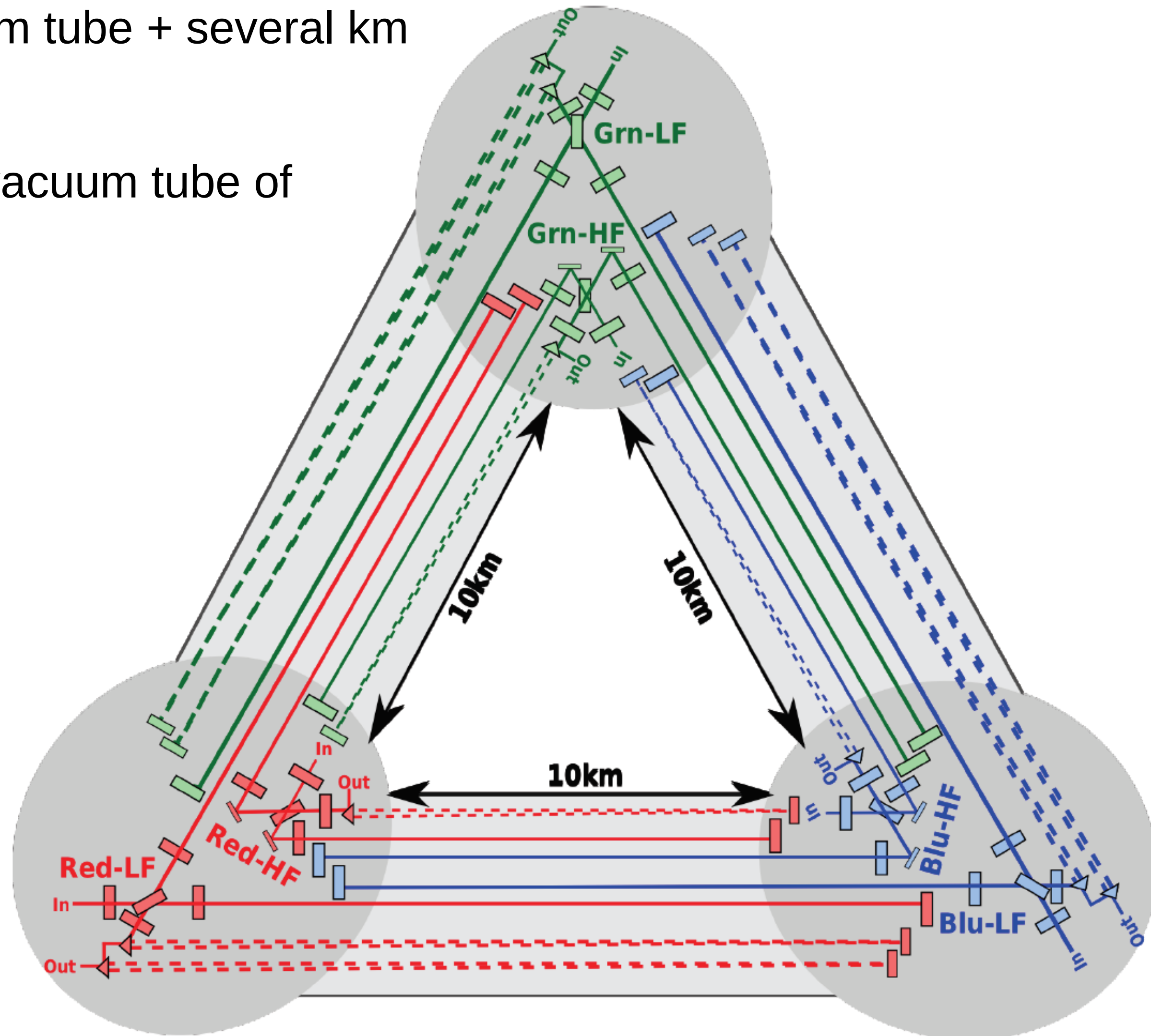
Each ITF has 20 km of main vacuum tube + several km of filter cavities

About 3 * (2 * 30 + 2) ≈ 130 km of vacuum tube of about 1 m diameter (assumption)

Tunnel inner diameter: 6.5 m

Tunnel will have concrete lining

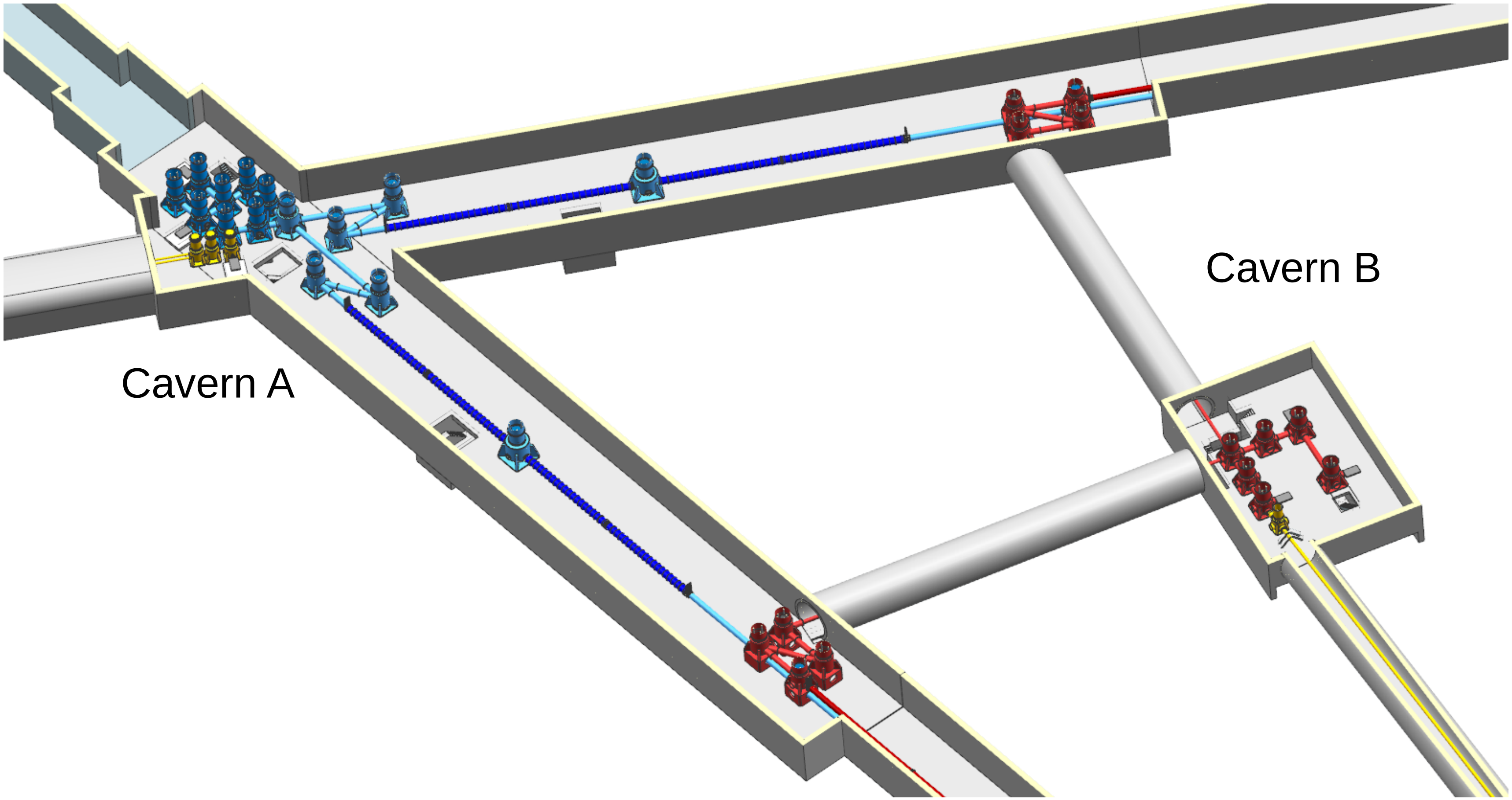




Einstein Telescope layout: corner station

Low frequency towers (blue): height = 20 m

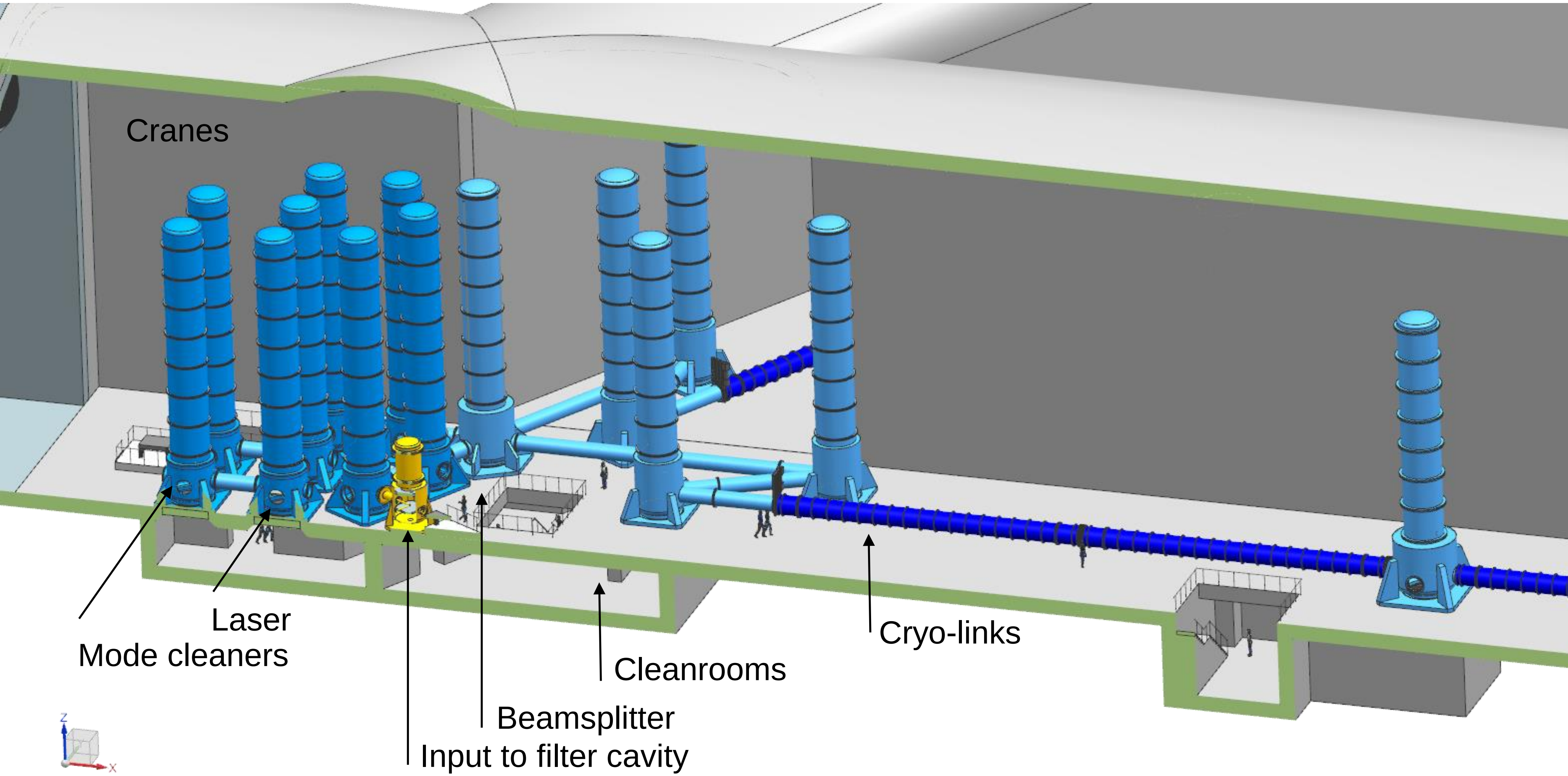
High frequency towers (red): height = 10 m



Towers for filter cavities and pick-off beams (yellow)

Corner station: cavern A

Houses the beamsplitter of the cryogenic low frequency interferometer
Towers are 20 m high. Cavern A dimensions are 20 m wide, 30 m high, 175 m long



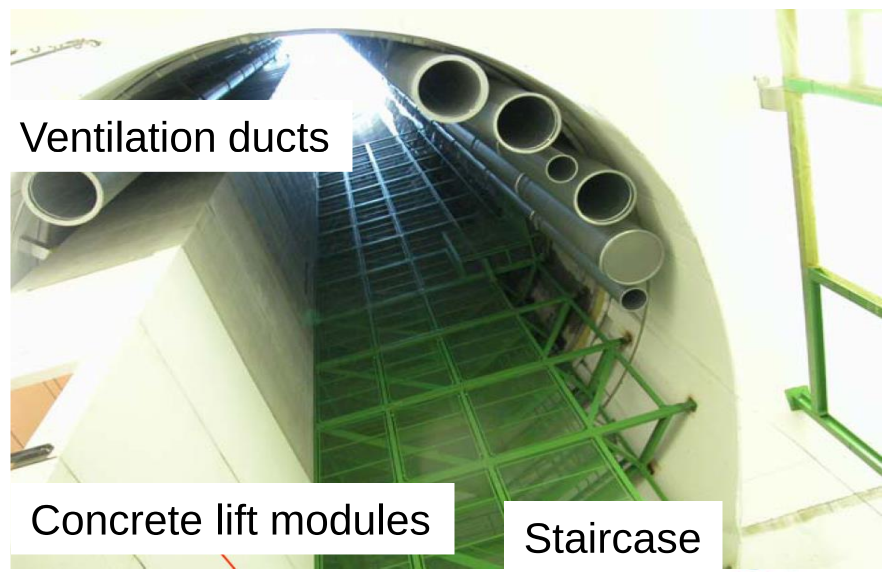
LHC underground caverns

Einstein Telescope

Cavern B: 25 m x 22 m x 38 m (about 21k m^3)

LHC project: CMS shaft

Diameter of about 20 m, while 10 m diameter is foreseen for Einstein Telescope



Vacuum system

KAGRA inauguration

Signing of the MOA with LIGO and VIRGO
Toyama, October 4, 2019

Einstein Telescope vacuum system

Three detectors that each consist of two interferometers: 6 ITFs in total

Each ITF has 20 km of main vacuum tube + several km of filter cavities

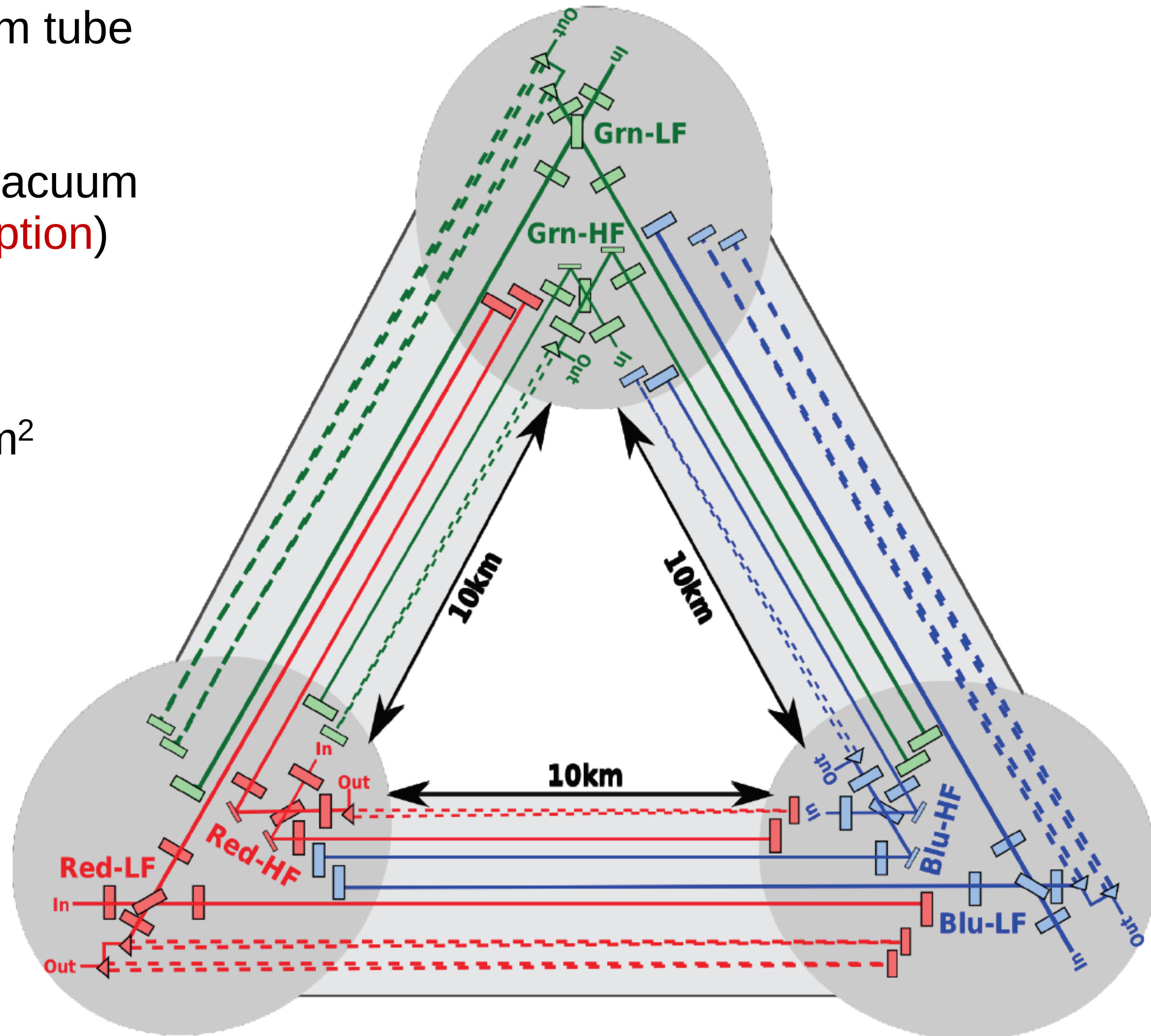
About 3 * (2 * 30 + 2) ≈ 130 km of vacuum tube of about 1 m diameter (assumption)

Total volume: about 120,000 m^3

Total surface area: about 420,000 m^2

Target pressure of < 10^{-10} hPa

Hydrocarbon pressure < 10^{-14} hPa



For comparison LHC at CERN:

- **Beam tubes: 2,000 m^3**
- Cryo-magnet insulation: 9,000 m^3
- Cryo distribution line: 5,000 m^3

Timeline Einstein Telescope

Sites qualification	now – 2023
ESFRI proposal submission	2020
ESFRI decision	2021
Research infrastructure operational design	2023 – 2025
Site decision	2025
Research infrastructure construction	2026 – 2032
Detector installation	2030 – 2034
Operation	2035

Underground construction and vacuum represent > 85% of the cost of ET

Preparation phase

Activity	Cost [M€]	Actualised cost [M€]	Start	End	Note
Site Qualification	15	14	2019	2022	Complex series of activities, going in parallel in the two candidate site, aiming to the qualification of the sites (compliance with the stringent ET requirements)
Funding schemes for the two sites	0	0	2019	2023	Definition of the two funding schemes for the two candidate sites. Interaction and negotiation between countries
Site Comparison	1	1	2022	2023	Evaluation of the two candidatures, using also external panels, experts and companies
RI Technical Design completion	38	31	2023	2025	Completion of the preliminary design, realisation of the definitive and operative design by specialised external companies.
Governance definition -ERIC	1	1	2021	2024	Study and definition of the governance structure of ET
Land acquisition	19	15	2023	2025	Acquisition of the land for the excavation and for the realisation of the surface infrastructures
Funding schemes for the two sites	0	0,0	2019	2023	Activity addressed to the definition of the financial schemes for the two candidatures
Technology development	95	81	2019	2028	R&D activity addressed to the development of the technologies needed for ET. This activity is already started since years and it is partially based on the technology developed for the upgrade of the current detectors
Detector design completion	2	2	2022	2025	Completion of the detector design after the selection of the site
Tot	171	145			

Construction phase

Activity	Cost [M€]	Actualised cost [M€]	Start	End	Note
Infrastructure costs	932	635			
Excavation	781	540	2026	2031	Excavation of the underground tunnels with TBMs and of the caverns. Cost based on the evaluation by two independent external companies
Direction of the civil works	9	6	2025	2032	Evaluation based on the 1% of the underground and surface infrastructures realisation cost
Civil works in surface	98	62	2028	2033	Realisation of the technical and civil infrastructures on the surface. Cost evaluation based on the Conceptual Design study
Services underground (ventilation, …)	44	27	2030	2033	Technical infrastructures serving the underground facilities and apparatuses
Detector costs	804	552			
Vacuum system	566	391	2026	2031	Vacuum plant, pumps and pipes
Optics and Laser	125	[illegible]	2026	2031	Main mirrors, auxiliary optics and lasers
Suspension system	48	33	2026	2031	Filtering and suspension systems
Cryogenics	45	31	2026	2031	Cryogenic plants
ET installation	20	11	2032	2035	Contracts and activities for the installation of the ET components
Total	1736	1187			

Gravitational waves, HEP and CERN

MOU in place to foster a strong CERN role in our quest for Einstein Telescope. Use JENAS initiative to strengthen the effort on joint R&D for current and future GW detectors. What about other fields?

Science

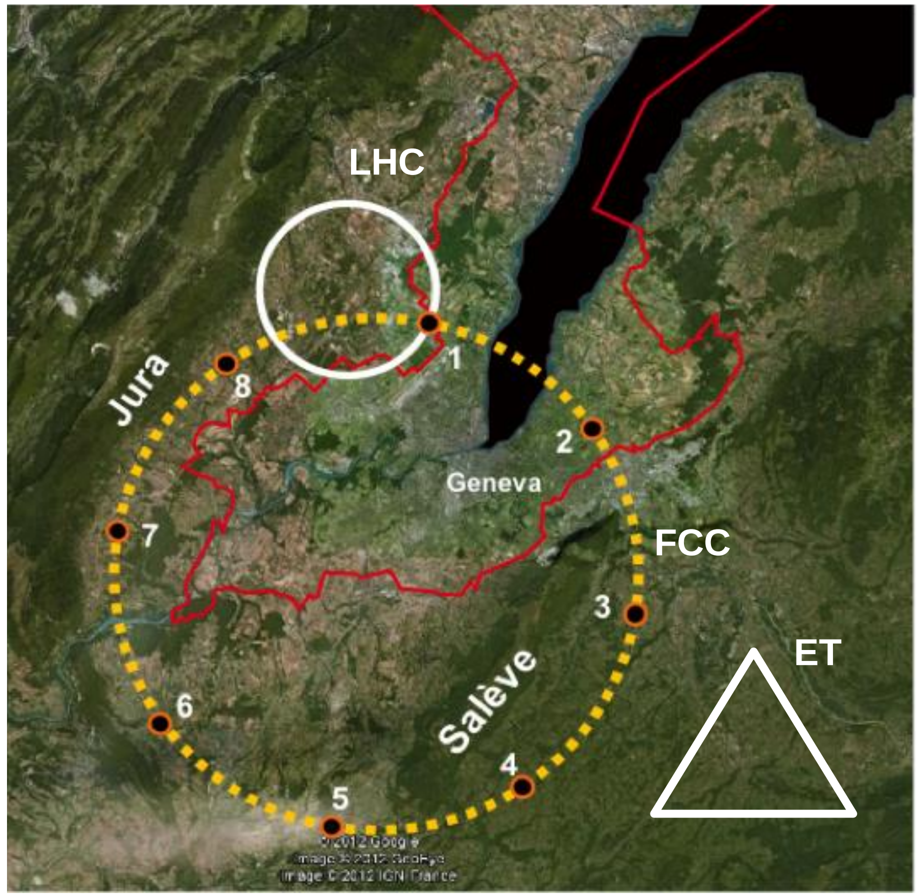
- Gravity is a fundamental interaction with most important open scientific issues
- GWs are the dynamical part of gravity
- Strong scientific interest from HEP
- Share facility with other fields in science

Time window

- ET Preparatory phase
- CERN projects

Instrumentation R&D

- Vacuum infrastructure
- Underground construction
- Cryogenics
- Controls



Thanks for your attention! Questions?